

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100	2101	2102	2103	2104	2105	2106	2107	2108	2109	2110	2111	2112	2113	2114	2115	2116	2117	2118	2119	2120	2121	2122	2123	2124	2125	2126	2127	2128	2129	2130	2131	2132	2133	2134	2135	2136	2137	2138	2139	2140	2141	2142	2143	2144	2145	2146	2147	2148	2149	2150	2151	2152	2153	2154	2155	2156	2157	2158	2159	2160	2161	2162	2163	2164	2165	2166	2167	2168	2169	2170	2171	2172	2173	2174	2175	2176	2177	2178	2179	2180	2181	2182	2183	2184	2185	2186	2187	2188	2189	2190	2191	2192	2193	2194	2195	2196	2197	2198	2199	2200	2201	2202	2203	2204	2205	2206	2207	2208	2209	2210	2211	2212	2213	2214	2215	2216	2217	2218	2219	2220	2221	2222	2223	2224	2225	2226	2227	2228	2229	2230	2231	2232	2233	2234	2235	2236	2237	2238	2239	2240	2241	2242	2243	2244	2245	2246	2247	2248	2249	2250	2251	2252	2253	2254	2255	2256	2257	2258	2259	2260	2261	2262	2263	2264	2265	2266	2267	2268	2269	2270	2271	2272	2273	2274	2275	2276	2277	2278	2279	2280	2281	2282	2283	2284	2285	2286	2287	2288	2289	2290	2291	2292	2293	2294	2295	2296	2297	2298	2299	2300	2301	2302	2303	2304	2305	2306	2307	2308	2309	2310	2311	2312	2313	2314	2315	2316	2317	2318	2319	2320	2321	2322	2323	2324	2325	2326	2327	2328	2329	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350	2351	2352	2353	2354	2355	2356	2357	2358	2359	2360	2361	2362	2363	2364	2365	2366	2367	2368	2369	2370	2371	2372	2373	2374	2375	2376	2377	2378	2379	2380	2381	2382	2383	2384	2385	2386	2387	2388	2389	2390	2391	2392	2393	2394	2395	2396	2397	2398	2399	2400	2401	2402	2403	2404	2405	2406	2407	2408	2409	2410	2411	2412	2413	2414	2415	2416	2417	2418	2419	2420	2421	2422	2423	2424	2425	2426	2427	2428	2429	2430	2431	2432	2433	2434	2435	2436	2437	2438	2439	2440	2441	2442	2
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**APPLICATION FOR
UNITED STATES LETTERS PATENT**

SPECIFICATION

BE IT KNOWN THAT I,

Maged G. Botros, a citizen of the United States of America, residing at 7843 Tylers Way, West Chester, Ohio 45069

have invented a new and useful

FUEL ADDITIVE COMPOSITIONS AND DISTILLATE FUELS CONTAINING SAME

of which the following is a specification.

5 **FUEL ADDITIVE COMPOSITIONS AND
DISTILLATE FUELS CONTAINING SAME**

BACKGROUND OF THE INVENTION

10 **Field of the Invention:** This invention relates to improved fuel additive compositions. The fuel additives of the invention provide improved low temperature flow and filterability to distillate fuels, such as diesel fuels, and are substantially non-discoloring and non-corrosive. Distillate fuels containing the fuel additive compositions are also provided.

15 **Description of the Prior Art:** Distillate fuels such as diesel fuels tend to exhibit reduced flow at low temperatures due in part to formation of waxy solids in the fuel. The reduced flow of the distillate fuel affects transport and use of the distillate fuels in refinery operations and internal combustion engine. This is a particular problem
20 during the winter months and especially in northern regions where the distillates are frequently exposed to temperatures at which solid formation begins to occur in the fuel, generally known as the cloud point (ASTM D 2500) or wax appearance point (ASTM D 3117). The formation of waxy solids in the fuel will in time essentially prevent the ability of the fuel to flow, thus plugging transport lines such as refinery
25 piping and engine fuel supply lines. Under low temperature conditions during consumption of the distillate fuel, as in a diesel engine, wax precipitation and gelation can cause the engine fuel filters to plug which can be simulated in the laboratory using tests such as the low-temperature flow test (LTFT). This test, ASTM Designation D 4539-98, estimates the filterability of diesel fuels in automotive
30 equipment at low temperatures. For the test, fuel samples are cooled at a prescribed rate and at the desired temperature and each 1°C interval thereafter, a specimen of the fuel is filtered through a 17µm screen utilizing a vacuum system. The minimum LTFT pass temperature is the lowest temperature at which the prescribed volume of

fuel (180 ml) can be filtered in 60 seconds or less. Alternatively, a single fuel specimen may be cooled in the above-described manner and tested at a specified temperature to determine whether it passes or fails at that temperature.

5 As used herein, distillate fuels encompass a range of fuel types, typically including but not limited to kerosene, intermediate or middle distillates, lower volatility distillate gas oils and higher viscosity distillates. Grades encompassed by the term include Grades No. 1-D, 2-D and 4-D for diesel fuels as defined in ASTM D975, incorporated herein by reference. The distillate fuels are useful in a range of
10 applications, including use in automotive diesel engines and in non-automotive applications under both varying and relatively constant speed and load conditions.

Distillate fuels are comprised of a mixture of hydrocarbons including normal and branched-chain paraffins, olefins, aromatics and other polar and non-polar
15 compounds, and cold flow behavior is a function of the relative proportion of these various hydrocarbon components. Normal paraffins typically have the lowest solubility and therefore tend to be the first solids to separate from the fuel as the temperature is decreased. At first, individual paraffin crystals will appear but as more crystals form they will ultimately create a gel-like network which inhibits flow. The
20 compositional makeup of fuels can vary widely depending on the crude oil source and how deeply the refiner cuts into the crude oil. With mounting pressure on refiners to increase production of distillate fuels, they are increasingly producing fuels with amounts and types of hydrocarbon components which render the fuels unresponsive to additives heretofore capable of imparting acceptable cold flow properties to the
25 fuels. These fuels are referred to within the industry as "hard-to-treat" fuels.

A number of compositional features can contribute to the unresponsiveness of hard-to-treat fuels to flow additives, including one or more of the following: a narrow molecular weight distribution of waxes; the virtual absence of high molecular weight
30 waxes; inordinately large amounts of very high molecular weight waxes; a higher

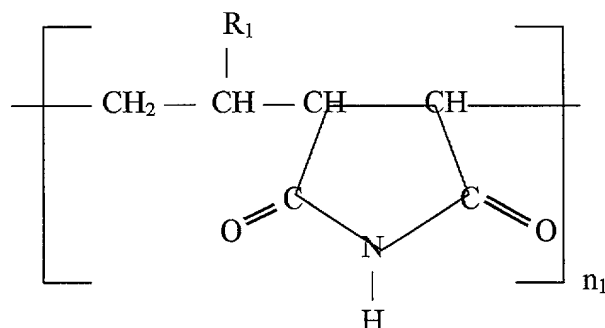
percentage (total) of wax; and a higher average carbon number for the normal paraffin component. While it is difficult to generate a single set of parameters which define hard-to-treat fuels, they are typically characterized by one or more of the following distillation parameters (as determined by test method ASTM D 86 incorporated herein by reference): the temperature differential between the 20% distilled and 90% distilled fractions; the temperature differential between the 90% distilled fraction and the final boiling point; and the final boiling point.

Useful cold flow improvers for distillate fuels, including hard-to-treat fuels, are disclosed in U.S. Patent No. 6,203,583. The cold flow additives of the invention are a combination of an ethylene/vinyl acetate/isobutylene copolymer with one or more of a maleic anhydride/ α -olefin copolymer component, a polyimide component and an alkylphenol component. Similar compositions useful as wax anti-settling agents and cloud point depressants for distillate fuels are disclosed in U.S. Patent Nos. 6,206,939 and 6,143,043, respectively.

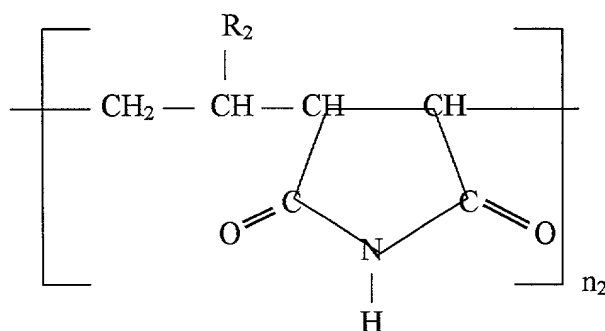
While certain of the above-mentioned additives do improve cold flow properties of distillate fuels to some extent, there continues to be a need for additives which exhibit enhanced performance, particularly for hard-to-treat fuels. For example, there is an ongoing need for cold flow improver additives which do not interact with the distillate fuel or other additives commonly contained therein and, in turn, discolor the fuel or cause the formation of undesirable deposits upon storage. Cold flow improver additives which tend to discolor distillate fuels, either by interaction with other additives, e.g., stabilizers, or by other means, can interfere with or mask dyes which are added to differentiate fuels, such as dyes added to tax-exempt off-road fuel. Accordingly, it would be highly advantageous if cold flow improver fuel additive compositions were available which provided both improved cold flow performance and stability for distillate fuels. It would be even more useful if the fuel additives were substantially non-acidic to prevent corrosion of metal storage tanks and transfer lines.

SUMMARY OF THE INVENTION

The present invention relates to improved fuel additive compositions and to distillate fuels, including hard-to-treat distillate fuels, containing said additives. The additives of the invention impart improved low temperature flow and filterability to distillate fuels and also serve to stabilize the fuels against the development of undesirable color or deposits upon storage. The fuel additives are a combination of an olefin/vinyl carboxylate polymer with first and second polyimides of specific structure. More specifically, the additives comprise (a) an olefin/vinyl carboxylate polymer selected from the group consisting of ethylene/vinyl acetate copolymers; ethylene/vinyl acetate/isobutylene terpolymers and mixtures thereof; (b) a first polyimide corresponding to the general formula



where R_1 is an alkyl group with an average carbon number of 22 to 26 carbon atoms and n_1 is from about 1.5 to 8; and (c) a second polyimide corresponding to the general formula



where R_2 is an alkyl group with an average carbon number greater than 30 and n_2 is

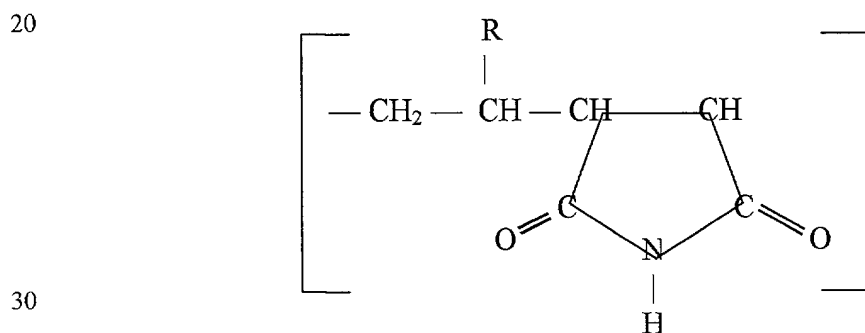
from about 1.5 to 8; said first polyimide and said second polyimide present at a weight ratio of 1:5 to 5:1 and the weight ratio of olefin/vinyl carboxylate polymer to the combined weight of said first and second polyimides ranging from 4:1 to 1:4.

5 Improved distillate fuel compositions containing 100 to 5000 ppm of the above-defined additives are also provided.

DETAILED DESCRIPTION

10 In accordance with the present invention, fuel additive compositions are provided which impart significantly improved cold flow properties, i.e., flowability and filterability, to distillate fuels and particularly hard-to-treat distillate fuels. Additionally, the fuel additive compositions of the invention do not adversely affect fuel stability.

15 The additive compositions of the invention are comprised of an olefin/vinyl carboxylate polymer and a mixture of a first polyimide and a second polyimide, said polyimides having repeating units corresponding to the general structure:

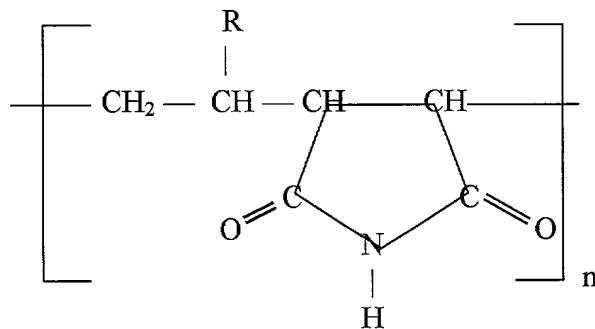


but differing in the number of carbon atoms in the pendant R group. The olefin/vinyl carboxylate polymer and first and second polyimides are present within prescribed weight ratio limits.

35

Useful olefin/vinyl carboxylate polymers include ethylene/vinyl acetate copolymers (EVA) and ethylene/vinyl acetate/isobutylene terpolymers (EVAiB) or combinations thereof. The EVA and EVAiB polymers will have weight average molecular weights in the range of about 1,500 to about 18,000, number average molecular weights in the range of about 400 to about 3,000 and a ratio of weight average molecular weight to number average molecular weight from about 1.5 to about 6. Preferably the weight average molecular weight ranges from about 3,000 to about 12,000 and the number average molecular weight ranges from about 1,500 to about 2,500. The EVA and EVAiB polymers have Brookfield viscosities in the range of about 100 to about 300 centipoise (cP) at 140°C. More typically the Brookfield viscosity is in the range of about 100 to about 200 centipoise. Vinyl acetate contents will range from about 25 to about 55 weight percent. Preferably the vinyl acetate content ranges from about 25 to about 45 weight percent and, even more preferably, from about 27 to about 38 weight percent. The branching index is from 2 to 15 and, more preferably, 5 to 10. The EVA copolymers and terpolymers are produced in accordance with known procedures. For example, the EVAiB copolymers are described in U.S. Patent Nos. 5,256,166 and 5,681,359 which are incorporated herein by reference.

A first and second polyimide are combined with the EVA, EVAiB or EVA/EVAiB blend to obtain the improved fuel additive compositions of the invention. The polyimides correspond to the general formula:



where R represents an alkyl moiety and n is the number of repeating units of the polyimide. The first and second polyimides utilized to obtain the improved compositions of the invention have different alkyl substituents, which are hereinafter respectively designated as R₁ and R₂. The number of repeating units of the first and second polyimide may be the same or different and are hereinafter respectively designated n₁ and n₂.

The alkyl substituent (R₁) for the first polyimide will be an alkyl group with an average carbon number of 22 to 26 carbon atoms. Preferably 60% or more of the alkyl substituents of the first polyimide will have 22 to 26 carbon atoms. Most preferably, the alkyl substituent R₁ of the first polyimide is comprised of at least 70% C₂₂₋₂₆ alkyl substituents. The number of repeating units (n₁) of the first polyimide will be from about 1.5 to 8 and the number average molecular weight (M_n) will range from about 600 to 8000. Weight average molecular weights (M_w) range from about 1500 to 15000.

The second polyimide will have an alkyl substituent (R₂) with an average carbon number substantially higher than that of the first polyimide. R₂ for the second polyimide will have an average carbon number greater than 30. Preferably 60% or more of the alkyl substituents of the second polyimide will have 30 to 36 carbon atoms. Most preferably at least 70% of the R₂ alkyl substituents will be C₃₀₋₃₆ alkyl substituents. The number of repeating units (n₂) for the second polyimide will be from about 1.5 to 8 and the number average molecular weight will range from about 650 to 9500. Weight average molecular weights for the second polyimide are from about 2000 to 21000.

Both polyimides are produced using known procedures wherein an α -olefin having the requisite number of carbon atoms is copolymerized with a substantially equimolar amount of maleic anhydride by means of free radical catalysis and in a subsequent reaction forming the corresponding polyimide by neutralizing with

ammonia at an elevated temperature. α -Olefins used in making the α -olefin/maleic anhydride copolymer precursors are mixtures of α -olefins having a distribution of carbon numbers so as to obtain the different alkyl substituents for the first and second polyimides. For example, to produce a first polyimide wherein 60% or more of the alkyl groups (R_1) have 22 to 26 carbon atoms, an α -olefin wherein 60% or more of the olefins contain 24 to 28 carbon atoms would be reacted with maleic anhydride to form the α -olefin/maleic anhydride precursor.

Effective fuel additive compositions are obtained by combining the EVA copolymer, EVAiB terpolymer or combination thereof and the first and second polyimides at a weight ratio of from 4:1 to 1:4 and, more preferably, from 2:1 to 1:2. The polyimide component in the foregoing weight ratios represents the total weight of both the first and second polyimides. The first and second polyimides are utilized at weight ratios from 1:5 to 5:1 and, more preferably, from 1:2.5 to 2.5:1. In one highly useful embodiment, 2 parts EVA, EVAiB, or mixture thereof are combined with 1 part first polyimide and 1 part second polyimide.

The fuel additive compositions of the invention are typically added to the distillate fuels at levels from about 100 ppm up to about 5000 ppm. While higher levels of additive can be used, any additional benefit obtained does not usually justify the additional cost. Especially useful additive levels are 150 to 3000 ppm and, more preferably, 200 to 2500 ppm.

The following detailed examples illustrate the practice of the invention in its most preferred form, thereby enabling a person of ordinary skill in the art to practice the invention. The principles of this invention, its operating parameters and other obvious modifications thereof, will be understood in view of the following detailed procedure. All parts and percentages in the examples are on a weight basis unless otherwise indicated.

To demonstrate the improved cold flow performance of the additive compositions, the additives were combined with various diesel fuels at weight concentrations ranging from 125 to 1000 ppm. All of the fuel formulations were prepared by the addition of a concentrate containing 10% of the additive composition (2 parts ethylene/vinyl carboxylate copolymer or terpolymer, 1 part first polyimide and 1 part second polyimide) in a mixed aromatic solvent (Aromatic 100). The desired concentration of additive in the fuel was obtained by varying the amount of concentrate added to the fuel.

Three olefin/vinyl carboxylate (OVC) polymers were utilized to prepare the various fuel additive compositions utilized in the examples and they are identified in Table 1. Polyimides used for the fuel additive compositions are identified in Table 2. Brookfield viscosities for the first polyimides (P1) and second polyimides (P2) used are provided. Brookfield viscosities for the polyimides were determined using hydrocarbon (Aromatic 100) solutions containing 35 weight % polyimide. The acid numbers for the α -olefin/maleic anhydride from which each of the polyimides was derived are included in the table.

Table I

	Polymer Type	Brookfield Viscosity at 140°C (cP)	VA Content (%)	Mn	Mw	Mw/Mn
OVC1	EVA copolymer	115	32	1889	3200	1.69
OVC2	EVAiB terpolymer	125	37	2237	11664	5.2
OVC3	a 1:1 blend of OVC1 and OVC2					

Table 2

	Brookfield Viscosity (cP/°C)	Precursor Acid Number
P1 A	15.1/23	130.5
P1 B	19.1/23	152.5
P2 A	18.8/45	128.7
P2 B	147.3/23	193.6

Various fuels were used in the examples to demonstrate the improved performance of the additive compositions of the invention. The fuels are listed in Table 3 with

distillation data for each determined in accordance with ASTM D 86. The data include the initial boiling point (IBP), final boiling point (FBP) and the temperature at which specific volume percentages of the fuel have been recovered from the original pot contents at atmospheric pressure. All temperatures are in °C.

5

Table 4 sets forth the distillation criteria generally utilized by the industry to characterize hard-to-treat fuels. This criteria utilizes the temperature difference between the 20% distilled and 90% distilled temperatures (90%-20%), the temperature difference between the 90% distilled temperature and final boiling point (FBP-90%) and the final boiling point. A 90%-20% temperature difference of about 100-120°C for middle distillate cut fuels is considered normal. A difference of about 70°-100°C is considered narrow and hard-to-treat and a difference of less than about 70°C is considered extremely narrow and very hard-to-treat. A FBP-90% temperature difference in the range of 25°C to about 35°C is considered normal. A difference of less than about 25°C is considered narrow and hard-to-treat. A difference of more than about 35°C is also considered hard-to-treat. A final boiling point below about 360°C or above about 380°C is considered hard-to-treat. Additional disclosure on hard-to-treat fuels is found in U.S. Patent No. 5,681,359, incorporated herein by reference. From an examination of the distillation data provided in Table 4, it will be observed that all of the fuels employed for the examples satisfy one or more of the above-described criteria and would therefore be considered hard-to-treat fuels.

Table 3

		Percent Distilled												
	IBP	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	95%	FBP	
Fuel 1	164	176	182	191	202	214	223	234	247	261	288	316	333	
Fuel 2	166	186	199	216	229	243	255	266	279	293	311	329	333	
Fuel 3	161	180	186	199	211	224	239	253	269	292	323	348	354	
Fuel 4	193	206	216	243	255	266	278	284	292	308	332	336	346	
Fuel 5	178	204	213	226	237	249	259	270	283	297	314	327	352	
Fuel 6	173	198	211	228	241	253	263	273	284	297	313	325	352	
Fuel 7	193	211	219	231	242	252	262	272	283	295	312	331	334	
Fuel 8	196	211	219	232	236	252	261	271	281	296	314	333	336	
Fuel 9	222	239	244	251	260	268	274	283	293	305	322	334	356	

Table 4

	90-20%	FBP-90%	FBP
Fuel 1	97	45	333
Fuel 2	95	22	333
Fuel 3	124	31	354
Fuel 4	89	14	346
Fuel 5	88	38	352
Fuel 6	85	39	352
Fuel 7	81	22	334
Fuel 8	82	22	336
Fuel 9	71	34	356

Examples 1-6

A series of six additive compositions were prepared in accordance with the invention and evaluated as cold flow enhancers for hard-to-treat fuel 1. The fuel additive compositions were utilized at a 500 ppm treat rate and evaluated using the LTFT test procedure (ASTM D 4539-98). In this instance, the fuels were cooled as prescribed by the test procedure and tested at -37°C to determine whether the fuels passed or failed at that temperature. A control, i.e., fuel 1 containing no additive, was also evaluated. Test results are tabulated below.

Example	Additive Composition	LTFT Results at -37°C
Control	None	Failed; 0 mls fuel was filtered
1	OVC1 + P1 A + P2 A	Passed; 180 mls filtered in 16 seconds
2	OVC2 + P1 A + P2 A	Passed; 180 mls filtered in 19 seconds
3	OVC3 + P1 A + P2 A	Passed; 180 mls filtered in 18 seconds
4	OVC1 + P1 B + P2 B	Passed; 180 mls filtered in 16 seconds
5	OVC2 + P1 B + P2 B	Passed; 180 mls filtered in 15 seconds
6	OVC3 + P1 B + P2 B	Passed; 180 mls filtered in 15 seconds

The improved filterability obtained by the use of the additive compositions of the invention is readily apparent from the data. Whereas it was not possible to pump any of fuel 1 at -37°C under the test conditions, all of the fuel samples containing the additives passed the LTFT test at -37°C. In fact, they all filtered in times well under 60 seconds which suggests they would pass the test at even lower temperatures and/or at even lower additive levels.

Example 7

To demonstrate the ability to reduce the fuel additive concentration the following experiment was conducted. For this experiment hard-to-treat fuel 2 was employed. The additive was employed at a concentration of 250 ppm and consisted of a blend of OVC1, P1 A and P2 A at a ratio of 2:1:1. The LTFT test was conducted at -27°C. The fuel containing 250 ppm of the additive composition passed the test. The prescribed volume (180 mls) was filtered in 31.7 seconds. The control, i.e., fuel

2 containing no additive, failed the test. Only 4 drops were filtered in the prescribed 60 second test interval. When the concentration of the additive composition in the fuel was lowered to 125 ppm, it was not possible to pass the LTFT test at -27°C. Only 25 mls of fuel 2 containing 125 ppm of the additive composition were filtered in 60 seconds.

Examples 8-13

The fuel additive compositions of Examples 1-6 were incorporated in fuel 3 at a 750 ppm treat level. All of the fuel blends containing the additive compositions passed the LTFT filterability test at -20°C. Results are tabulated below along with the results obtained for the control.

Example	Additive Composition	LTFT Results at -20°C
Control	None	Failed; 0 mls fuel was filtered
8	OVC1 + P1 A + P2 A	Passed; 180 mls filtered in 15 seconds
9	OVC2 + P1 A + P2 A	Passed; 180 mls filtered in 11 seconds
10	OVC3 + P1 A + P2 A	Passed; 180 mls filtered in 12 seconds
11	OVC1 + P1 B + P2 B	Passed; 180 mls filtered in 16 seconds
12	OVC2 + P1 B + P2 B	Passed; 180 mls filtered in 19 seconds
13	OVC3 + P1 B + P2 B	Passed; 180 mls filtered in 14 seconds

The significance of the LTFT results set forth above is even more apparent when compared with the results obtained using the ethylene/maleic anhydride precursors of P1 A and P2 A. When Example 9 was repeated except that the corresponding ethylene/maleic anhydride copolymer precursors were substituted for P1 A and P2 A, the fuel failed the LTFT test at -20°C. Only 152 mls of the fuel was filtered within the prescribed 60 second test interval.

Examples 14-19

Whereas the foregoing examples clearly illustrate the unexpected and significant improvement in LTFT filterability obtained using the compositions of the invention, additional fuel formulations were prepared and evaluated to demonstrate their improved stability, as evidenced by the elimination or minimization of formation

of undesirable color bodies and/or deposits upon aging. For these formulations fuels 4-9 were employed. To each fuel was added 1000 ppm of the additive composition of Example 9 (2 parts OVC 2 with 1 part P1 A and 1 part P2 A). For comparison, each fuel was also formulated with 1000 ppm of a composition comprised of 2 parts OVC2 with 1 part each of the ethylene/maleic anhydride copolymer precursors of P1 A and P2 A. The fuel formulations were heated for 16 hours at 50°C and then stored at room temperature for 45 days. The fuel samples were visually inspected at the beginning and end of the test period and the results recorded. Absorbance and percent transmittance were also determined spectrophotometrically for the aged fuel samples 14-18 and their corresponding comparative formulations. Spectrophotometric measurements were made in the visible (500 nanometer) range. Results are reported in Table 5. It is apparent from the data that the fuels formulated with the additives of the invention have significantly improved stability compared to the fuels formulated with the precursor ethylene/maleic anhydride copolymers. Very little if any change in color was observed upon aging with the fuel formulations of the invention and no undesirable deposits were formed.

Table 5

Example	Visual			
	Initial	After Storage	Absorbance	% Transmittance
14	Clear	Clear	0.021	95.4
Comparative 14	Clear	Turbid	0.198	63.4
15	Yellow	Yellow	0.226	59.3
Comparative 15	Yellow	Brown	0.407	39.2
16	Light brown	Light brown	0.686	20.6
Comparative 16	Light brown	Black	1.078	8.4
17	Light yellow	Light yellow	0.00	100
Comparative 17	Light yellow	Mid-dark yellow	0.025	94.1
18	Yellow	Yellow	0.021	95.3
Comparative 18	Yellow	Dark yellow	0.08	83.2
19	Clear	Clear	---	---
Comparative 19	Clear	Dark brown-black deposit formed	---	---